

# Management Effects on Soil Organic Carbon in Texas Soils

**Kenneth N. Potter**

USDA-ARS, Grassland Soil and Water Research Laboratory, Temple, TX

**Paul W. Unger**

USDA-ARS, Conservation and Production Research Laboratory, Bushland, TX

**H. Allen Torbert**

USDA-ARS, National Soil Dynamics Laboratory, Auburn, AL

*Soils contain* a vast reservoir of organic carbon and, with the selection of appropriate management strategies, may store even more C that would otherwise be in the atmosphere. Previous soil management regimes have resulted in a large decrease in soil C storage. An estimated 5000 Tg C have been lost from U.S. soils as a result of cultivation (Lal et al., 1999). Recent studies have been directed to increasing soil organic carbon (SOC). A majority of these studies have been conducted in the northern portions of the United States. However, there is a need to determine management effects in soil and climatic conditions other than in the Corn Belt to determine the limits of possible soil C sequestration. Texas is a large state with diverse soils and climatic conditions. Temperatures at the Texas study sites vary from similar to those occurring in the Corn Belt to much warmer than the Corn Belt (Table 7-1). Annual rainfall amounts at the study sites range from 430 to 1160 cm.

Research regarding management effects on soil C has been ongoing in Texas for more than 40 years. Most research has been clustered in three general regions: the Texas panhandle, with research reported from the Lubbock and Bushland region; central Texas, with research conducted near the Temple and College Station region; and the gulf and lower Rio Grande Valley region, with research reported from near Corpus Christi and Weslaco.

Research regarding SOC in Texas has generally been conducted in three general topic areas: (i) tillage management practices in which the effect of tillage and no-till crop production systems has been evaluated; (ii) cropping intensity practices in which the effect of fallow practices, crop rotations, and double-cropping are evaluated; and (iii) the effect of returning previously cropped soil to grasses. These studies typically include comparisons to native grasslands and may also include the effect of the conservation reserve program on soil properties. Most

**Table 7–1. Climatic and soils data for the study sites.**

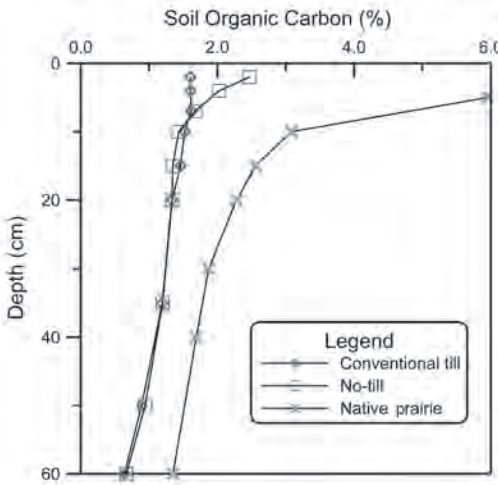
Site	Mean annual temperature	Mean annual rainfall	Predominant soil series	References
	°C	mm		
Big Spring	18	430	Patricia FS	Gebhart et al., 1994
Bushland	14	470	Pullman CL	Potter et al., 1998 Schomberg and Jones, 1999 Unger, 1968, 1991
College Station	20	980	Weswood SiCL	Wright and Hons, 2004, 2005a, 2005c
Corpus Christi	22	765	Orelia SiCL	Potter et al., 1998 Salinas-Garcia et al., 1997 Wright et al., 2005
Lubbock	15	508	Amarillo SL Olton CL Patricia LS	Bronson et al., 2004
Overton	19	1160	Darco FSL	Wright et al., 2004
Temple	19	860	Houston Black C	Potter et al., 1998, 1999 Potter and Derner, 2006
Weslaco	23	Irrigated	Hidalgo SCL	Zibilske et al., 2002

studies contain elements of two or more of these three general topics. Our objective is to discuss individual studies as they apply to one or more of the general topics and then provide a summary of the research results from across the state.

### Tillage Management Practices

Management effects on SOC were determined at three locations in Texas—Bushland, Temple, and Corpus Christi—where a comparison of no-till and other management practices had been in place for 10 or more years. Typical results from the Temple location are shown in Fig. 7–1 (Potter et al., 1998). The sites varied in mean annual temperature and rainfall amounts (Table 7–1). At Bushland, no-till increased SOC concentration in the surface 7 cm compared to a stubble-mulch tillage regime. The SOC concentrations were similar in the 7- to 20-cm depth increment at Bushland. At the Temple location, differences in SOC concentration were found in the surface 20 cm. The SOC concentration increased with no-till in the surface 0- to 4-cm depth increment, but observed increase in SOC was less in the 7- to 20-cm depth increment when compared to soil from the chisel-plow system.

At Corpus Christi, a crop rotation of 4 yr of corn (*Zea mays* L.) followed by 4 yr of cotton (*Gossypium hirsutum* L.) was established and sampled after 14, 16, and 20 yr. After 14 yr, no-till had not significantly altered the SOC concentration compared to moldboard-plow or chisel-plow management systems when sampled after either corn or cotton. Salinas-Garcia et al. (1997) reported SOC content was measurably increased after 16 yr of continuous tillage management for all three management systems. It should be noted that the crop sequence was in the last year of corn when these soil samples were obtained. No-till resulted in the higher



**Fig. 7-1. Typical results of no-till and chisel-plow tillage management systems on the soil organic carbon profile. A native prairie profile is shown for comparison. (From Potter et al., 1998.)**

amounts of SOC in the surface 20 cm than chisel-plow and moldboard-plow management systems. When sampled after 20 yr, no-till increased SOC concentration in the surface 2.5 cm for cotton but not for corn (Wright et al., 2005). Few tillage effects were found in subsurface soils. For corn, SOC was 11% higher under no-till than other tillage regimes at 0 to 2.5 cm, but was 22% lower under no-till at 2.5- to 20-cm depths. Averaged over depths, SOC for cotton no-till was 24% greater than for moldboard plow. Overall, studies indicate that potential to sequester SOC in the soils at Corpus Christi with this crop rotation and intensity appears limited.

At Bushland, a cropping and management study compared no-till and stubble-mulch with wheat (*Triticum aestivum* L.) alternated with grain sorghum (*Sorghum bicolor* L. Moench.) (Jones and Popham, 1997). After 10 yr, the total mass of SOC in the surface 20 cm was increased with no-till management as compared to stubble-mulch tillage. A difference was also noted between crops, with a wheat crop resulting in more SOC than a grain sorghum crop, despite the grain sorghum producing more than three times as much grain and up to twice as much aboveground biomass remaining after harvest than for wheat. A similar effect of a wheat crop was found at the Temple location where a study compared the effects of no-till and chisel-plow management with a wheat, corn, grain sorghum annual crop rotation (Potter et al., 1998). After 10 yr, the total SOC mass was similar for both no-till and chisel-plow management systems after a wheat crop. However, when sampled after the corn crop at the Temple location, significantly greater amounts of SOC mass were found in the no-till soil than in the tilled soils. While tillage treatments were significant after the corn crop, total SOC mass was slightly reduced after the corn compared to amounts occurring after wheat. The chisel-tilled soils had much lower SOC mass after corn compared to the SOC in the chisel-tilled soils after wheat.

The rate of SOC sequestration under no-till management was estimated by taking the difference between the mean no-till value and the mean value reported for tilled plots (Potter et al., 1998). It was assumed that the rate of change in the tilled plots was negligible, and the data was normalized by dividing by the number of years of continuous management, which ranged from 10 to 16 yr across the

sites studied. No-till resulted in positive rates in 16 of 20 possible comparisons. The largest change in SOC due to no-till occurred with fertilized wheat at Bushland, while no-till resulted in a loss of SOC with ridged corn with high fertilizer rates at Corpus Christi.

Climatic effects on SOC sequestration were estimated by selecting the most similar crops and management systems for each location (Potter et al., 1998). Differences in annualized total SOC accumulation rates between no-till management and chisel-plow management at Temple and Corpus Christi, and no-till and stubble-mulch tillage at Bushland were related to mean average temperature and mean annual rainfall.

$$\Delta\text{SOC} = -17.2 \text{ MAT} + 619, r^2 = 0.99$$

$$\Delta\text{SOC} = -0.23 \text{ MAR} + 455, r^2 = 0.40$$

Where  $\Delta\text{SOC}$  is the change in SOC mass ( $\text{kg C ha}^{-1} \text{ yr}^{-1}$ ), MAT is the mean annual temperature ( $^{\circ}\text{C}$ ), and MAR is the mean annual rainfall (mm). These results imply that no-till is more effective in sequestering SOC in cooler and drier climates than in warmer and more humid areas.

### Cropping Intensity

A 24-yr cropping intensity and tillage management study was conducted near Bushland in which wheat was grown in either a wheat-fallow rotation (one crop every 2 yr) or in a continuous wheat rotation (one crop per year) (Unger, 1968). Tillage practices ranged from one-way plowing, field cultivation, and stubble-mulch tillage for continuous wheat, to one-way plowing, stubble-mulch, and delayed stubble-mulch for the wheat-fallow rotation. In the delayed stubble-mulch system, no tillage was performed until weed growth started the spring following harvest. This resulted in six or seven tillage operations in the delayed stubble-mulch system compared to up to 10 tillage operations in the regular stubble-mulch system. All of the tillage practices resulted in a decrease in organic matter from the initial 2.44% SOC concentration measured in 1941. In 1966, differences in soil organic matter due to tillage practices were not significant where wheat was grown continuously, averaging 1.79% in the surface 15.2 cm. However with continuous wheat, SOC averaged 1.76% compared to 1.59% for wheat-fallow. In the wheat-fallow crop rotation, soil organic matter in the surface 15.2 cm of soil in 1966 was highest for the delayed stubble-mulch system (2.06%) compared to the one-way plow (1.59%) and stubble-mulch (1.66%) systems.

With the introduction of no-till, cropping intensity interacted with tillage management practices to alter SOC accumulation in the southern High Plains near Bushland (Potter et al., 1997). This 10-yr study determined the effect of no-till and stubble-mulch tillage practices on four crop rotations: continuous wheat, continuous grain sorghum, wheat-fallow-sorghum-fallow (two crops in 3 yr) and wheat-fallow (one crop in 2 yr). Compared to the stubble-mulch management practices, total SOC content in the surface 20 cm was increased by 5.6  $\text{Mg C ha}^{-1}$  in the continuous wheat with no-till management and by 2.8  $\text{Mg C ha}^{-1}$  in the continuous grain sorghum with no-till management. Differences were not significantly different between tillage management systems with the wheat-fal-

low and the wheat–fallow–sorghum–fallow cropping systems. Including fallow in the crop rotation effectively eliminated soil C accumulation in this study.

No-till resulted in more SOC in the surface 8 cm after 12 yr than stubble-mulch tillage when averaged across continuous wheat, continuous sorghum, and a wheat–sorghum–fallow crop rotation at Bushland, Texas (Schomberg and Jones, 1999). The SOC in the 0- to 2-, 2- to 4-, and 4- to 8-cm depths was 9.9, 10.4, and 11.1 kg m<sup>-3</sup> in stubble-mulch and 12.6, 12.5, and 11.9 kg m<sup>-3</sup> in no-till, respectively. In this study, significant negative correlations were found between grain yield and SOC. Greater yields and residue production usually increase C inputs to the soil and increase SOC. At this location, however, water availability is a limiting factor under dryland conditions (Table 7-1). The negative correlation may indicate that greater water demands of higher-yielding crops create dryer soil conditions, which in turn limit microbial activity and population size. A significant effect of decreasing fallow length was also noted as increasing SOC content in continuous wheat compared to continuous sorghum. Continuous wheat (one crop per year) also conserved more SOC than all phases of a wheat–sorghum–fallow (two crops in 3 yr) crop rotation.

An intensive double-cropping rotation, sorghum–wheat–soybean (*Glycine max* L. Merr.) (three crops in 2 yr), resulted in greater SOC concentration in the surface 5 cm than a continuous sorghum cropping system (one crop per year) (Wright and Hons, 2005b). No-till increased the concentrations in the surface 5 cm for both the continuous sorghum and sorghum–wheat–soybean cropping systems compared to a conventional tillage regime of disking, chisel plowing, disking, and ridging. Carbon concentrations were greater in the conventional tillage systems in the 5- to 15-cm depth increments.

Comparisons of other intensive crop rotations had similar but not identical results (Wright and Hons, 2004). With conventional tillage, a sorghum–wheat–soybean rotation (three crops in 2 yr) had a lower SOC concentration in the surface 5 cm than a wheat–soybean double-crop rotation (two crops per year), but higher than annual soybeans. With no-till, the sorghum–wheat–soybean rotation had the greatest SOC concentration, followed by the wheat–soybean rotation, with annual soybeans having the lowest SOC concentration. There were only minor differences in SOC concentration in the 5- to 15-cm depth increment among rotations and tillage regimes. When the C storage was expressed on a mass basis, results were somewhat different. No-till had a larger C storage than conventional tillage for all crop rotations. Differences among crop rotations were not significant in the 0- to 5-cm depth. At 5 to 15 cm, the sorghum–wheat–soybean and continuous soybean rotations had greater C storage under no-till than conventional tillage, but not for the wheat–soybean rotation. No-till management increased SOC storage compared to conventional tillage by 70, 51, and 72% at 0 to 5 cm, and 24, 10, and 51% at 5 to 15 cm for the sorghum–wheat–soybean rotation, wheat–soybean double-cropping, and continuous soybean, respectively. The greatest impact on SOC was achieved by combining no-till with intensive cropping systems.

In the lower Rio Grande Valley, after 8 yr of irrigated, double-cropped cotton and corn (two crops in 1 yr), no-till resulted in a greater SOC in the surface 4 cm of soil, increasing the organic C concentration 58% over that found in the surface of moldboard-plowed soil (Zibilske et al., 2002). In the 4- to 8-cm depth, SOC was 15% greater than in the moldboard-plow treatment. The amount of C increase in the soil at this site, with a mean annual temperature of 23°C (Table 7-1),

is small compared to what may be expected with double-cropping in cooler climates. The relatively low amount of readily oxidizable C in all tillage treatments suggests that most of the SOC gained is humic in nature and would be expected to improve C sequestration in this soil.

### Grass Establishment

Potter et al. (1999) determined the rate of increase in SOC over time by establishing grasses in soils that had been previously tilled and cropped primarily to cotton. The soils were all high-clay Vertisols (Udic Haplusterts) located in central Texas near Waco. Surface (0–5 cm) SOC concentrations ranged from 4.44% to 5.95% in native grasslands and 1.53% to 1.88% in soils that remained in row-crop production. Carbon concentrations in restored grasslands were intermediate to the croplands and native grassland soils. The SOC mass in the surface 120 cm of the agricultural soils was 25 to 43% less than that of the native grassland sites. After the establishment of grasses, SOC mass increased in a linear manner over time periods from 6 to 60 yr at a rate of  $0.45 \text{ Mg ha}^{-1} \text{ yr}^{-1}$  (Fig. 7–2). Within the extended time period in this study, C mass increased up to 60-cm depths in the 60-yr reestablished grass site.

Near Lubbock, Conservation Reserve Program (CRP) sites were planted to grasses—blue grama (*Bouteloua gracilis*), Old World bluestem [*Bothriochloa ischaemum* (L.) Keng], sand dropseed (*Sporobolus cryptandrus*), sideoats grama (*Bouteloua curtipendula*), silverleaf nightshade (*Solanum elaeagnifolium*), and weeping lovegrass (*Eragrostis curvula*)—that had been in place from 9 to 15 yr (Bronson et al., 2004). The SOC increased in the surface 5 cm compared to cotton-cropped soils. There was no difference between CRP and cropped soils at depths from 5 to 15 cm. This is in contrast to results reported by Gebhart et al. (1994) in which the CRP increased SOC to a 20-cm depth compared to cropped soils. In both studies, the increase in SOC was small, and the CRP soils had a much lower SOC content than the native range sites.

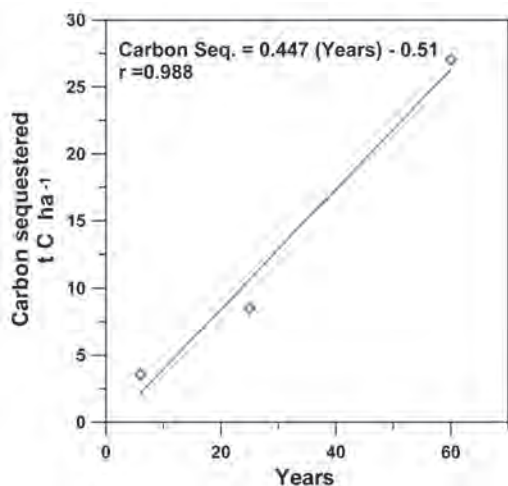


Fig. 7–2. Increase in soil organic carbon with increasing number of years in grass. Seq., sequestered. (From Potter et al., 1999.)

Common and coastal bermudagrass (*Cynodon dactylon* L. Pers.), established near Overton on soil previously used for pine (*Pinus* spp.) tree production, increased SOC concentration in the 0- to 15-cm depths for periods up to 26 yr (Wright et al., 2004). High-intensity grazing resulted in lower increase in SOC concentration over time compared to low-intensity grazing.

Grazing intensity affected the SOC content differently on two degraded soils in southern Oklahoma (Potter et al., 2001). Total SOC mass in the surface 60 cm of a Durant loam (Udertic Argiustolls) averaged across treatments was 96 Mg C ha<sup>-1</sup> compared to 57 Mg C ha<sup>-1</sup> in a Teller silt loam soil (Udic Argiustolls). In the Durant soil, organic C decreased as grazing intensity increased, with the largest amount occurring in a nongrazed enclosure. In contrast, the Teller soil had similar amounts of organic C across a range of grazing intensities, with the smallest amount found in a nongrazed enclosure.

The particulate organic C, defined as the organic C in the 53- to 2000- $\mu$ m size fraction, and mineral-associated C, defined as the less than 53- $\mu$ m size fraction, were determined for a similar set of treatments in central Texas (Potter and Derner, 2006). Native grassland contained the largest amounts of total organic C, while restored grasslands and agricultural soils contained similar amounts of total organic C. Both particulate organic C and mineral-associated C pools were reduced beyond the depth of tillage in the restored grassland and agricultural soils compared to the native grassland soils. The restored grassland soils had larger particulate organic C content than the agricultural soil, but the increase was limited to the surface 5 cm of soil. Trends in particulate organic C accumulation over time from 9 to 30 yr were not significant in this study.

## General Conclusions

Conservation tillage practices can increase SOC in Texas, although it may be necessary to adopt special procedures to be successful. In the dryer regions of the Texas High Plains, crop rotations must be changed away from traditional fallow farming practices. Continuous cropping with no-till management practices will often increase SOC content. In the warmer and dryer areas in the lower Rio Grande Valley, irrigated double-cropped corn and cotton combined with no-till management increased SOC content, although at a very slow rate. No-till management with high-residue crops or double-cropping increased SOC in the high-clay soils of central Texas. One of the most feasible methods to increase SOC in Texas soils is to convert to a grass-based production system. This fits well with the extensive cattle grazing operations found throughout the state. Soil properties should be considered if increasing SOC is also a goal of the cattle feeding operation.

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